SPECIAL ARTICLE

Efficacy of Bomb Shelters: With Lessons From the Hamburg Firestorm*

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ABSTRACT: Shelters for protection against the effects of nuclear weapons are often stated to be useless, largely because of firestorms. Recent models purport to show that nuclear weapons are more likely to cause firestorms than previously thought. These controversial models are based on uncertain assumptions, which are difficult or impossible to test. Regardless of the predictive validity of fire models, conclusions about the ability of shelters to protect their occupants against firestorms, if they occur, are based primarily on historical experience. A review of the original data from the Hamburg firestorm shows that almost all persons in adequate shelters survived, contradicting a currently prevailing belief that all died. The results of the strategic bombing during World War II and of nuclear weapons tests show that a considerable level of population protection can be achieved through attention to proper shelter design.

ON THE NIGHT of July 27-28, 1943, a terrible firestorm was caused by Allied incendiary bombing of the city of Hamburg, Germany. At the time, an estimated 1.5 million people were in the Hamburg metropolitan area; 470,000 were in the damaged area, and 280,000 were in the 14 km^2 (5 square miles) firestorm area.[1(p10)] Of these 280,000 people, about 50,000, or 18%, were killed in the attack. Thus about 230,000, or 82%, survived. The chance of survival depended largely upon the type of shelter.

Official reports by American, British, and German authorities include definitive, detailed statements by persons actually in Hamburg at the time of the raids and by their contemporaries. All of these sources are in basic agreement. According to the US Strategic Bombing Survey, "No evidence was found of a single death in a bunker during these large city fires."[2(p25)] With specific reference to Hamburg, the report noted that "casualties in shelters were principally confined to apartment building shelters."[2(p22)] A report by the British Home Office stated, "It can be concluded that all those sheltering in bunkers survived."[1(p11)] The Police President of Hamburg (who was responsible for firefighting and other civil defense functions) wrote: "In no instance either in bunkers or surface shelters did shelterees come to harm from the heat, nor did they have to leave the shelters prematurely."[3(p161)]

In recent years, a remarkable myth has arisen. It holds that the Hamburg firestorm was unsurvivable, even in shelters. Belief in this myth is one political reason for the fact that Americans, unlike citizens of other nations that are potential targets for nuclear weapons, have virtually no shelters to prevent blast, fire, and radiation injuries in the event of nuclear attack, whether in generalized war or by terrorists.[4]

Indeed, if any nuclear weapon would inevitably cause a firestorm, and if no shelter is effective against firestorms, then shelters would be useless in a nuclear attack. However, these premises are false, and therefore the conclusions following from them are also false. In this discussion, we examine the anatomy of this dangerous myth, the truth concerning the firestorm, and the evidence that properly constructed shelters could save lives, even in the event of a nuclear attack.

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SOURCES OF THE MYTH

In the introduction to the series of articles entitled "The Medical Consequences of Thermonuclear War," which appeared in *The New England Journal of Medicine* in 1962, it is asserted (without references) that "in the [case of multimegaton saturation bombing of cities], no system of shelters would spare the people of the urban and industrial centers from blast and fire."[5] One article in the series stated that "the Hamburg experience is particularly germane in relation to the shelter problem, for as Caidin points out, only those who fled their shelters in the early stages of fire had any hope of reaching safety."[6]

In the years since 1962, this assertion has become dogma to some US physicians. For example, it is stated without attribution that "anyone caught in the fire zone would be promptly roasted, and those in underground shelters would be either suffocated from lack of oxygen or asphyxiated by carbon dioxide or carbon monoxide, as occurred in Hamburg and Dresden."[7]

A firestorm allegedly makes "all conventional sheltering attempts worse than useless. At these temperatures, and with the exhaustion of oxygen supplies and the accumulation of toxic gases, shelters become crematoria."[8]

It is asserted that the argument for improved civil defense, made recently by former Federal Emergency Management Agency (FEMA) director Julius Becton, "can be deflected with... a study of the experience of sheltered populations of Hamburg and Dresden."[9]

In all of the works we have cited, the only actual reference to a source of data concerning the Hamburg firestorm was given in the 1962 symposium[6(p1131)]: a book entitled *The Night Hamburg Died* by Martin Caidin, an author of science fiction novels and of fiction and nonfiction books on military history, especially military aircraft of World War II. Caidin offers (without attribution) a graphic description of those who took shelter during the firestorm:

> Sealed into their cellars, huddling behind heavy doors, they have closed themselves off from the outer world and the oceans of fire splashing around and over their warrens.
>
> No flame ever touches them, but not a man, woman, or child survives. Not a single living soul. Not a human being, an animal, not even the smallest rodent, not a single insect, survives the area of the firestorm. In the shelters the heat continues to rise.... The occupants lean back, trying to conserve their strength. Unknown to them, the oxygen they need so badly begins to disappear....[10(pp103-104)]

At a recent symposium held under the auspices of the Institute of Medicine of the National Academy of Sciences (NAS), it was stated that there are "no data regarding survival in the [Hamburg] fire zone" and that the "complete absence of any tabulated data for a circumstance that is relatively well documented remains conspicuous."[11(pp58-59)] Yet this same work cites as an authoritative reference the original source material,[3] from which we obtained many of the figures in the present article.

The Police President's original report has recently been reviewed and updated by Hans Brunswig,[12] the department chief of the technical service on the staff of the Hamburg Fire Department, who was an eyewitness to the firestorm. Brunswig was familiar with the book by Caidin, which he called *"den infamen Schwindelbericht"* (the infamous swindle-report). He stated that Caidin allegedly got the story from an unnamed American army officer, along with the (false) assertion that the documents about the event were destroyed and all statements by survivors were stricken from the record forever.[12(pp245-246)]

All sources agree in their descriptions of the inferno that existed within the firestorm area; the differences concern the fate of persons in adequate shelters.

FIRESTORMS

There is no generally accepted definition of a firestorm, though most would agree on a description of the phenomenon: many fires merge to form a single convective column of hot rising gases, causing winds to rush inward. Virtually everything combustible within the firestorm area is destroyed.[13(p299)] Temperatures in the firestorm area of Hamburg exceeded 800 C,[14(p89)] and wind velocities reached 20 m/sec (45 mph), or up to 50 m/sec (112 mph) in the estimation of some firefighters.[15]

Special conditions were needed to produce the firestorms of World War II: suitable weather conditions (in Hamburg there was an unusual combination of high temperatures and low humidity for some days preceding the firestorm[16(p259)]), dense construction with flammable materials providing a high fuel load, and proper use of incendiaries combined with limited use of high explosives. American attempts to develop a mathematical formula for the generation of firestorms were unsuccessful.[12(p273)] Despite assiduous efforts, the British were unable to cause a firestorm in Berlin. According to German civil defense specialist Hans Rumpf,[14] this was due to the damp weather conditions, to the city plan, with its subdivision into fire districts, and to Berlin's stronger antiaircraft defense and its 10,000 man fire brigade, three times the size of Hamburg's.[12(p307)]

Also, after 1944, the Allies were unable to start another firestorm in Hamburg, but they did cause one in Dresden in 1945 and in several other cities.[17]

The mass fire that occurred after the atomic bomb was dropped on Hiroshima is considered by some to meet the criteria for a firestorm. Some say that no firestorm occurred at Nagasaki[13(p304)]; others say that small firestorms developed in some areas.[18(p81)]

The original 1983 report on "nuclear winter" assumes that 5% of urban fires resulting from a nuclear exchange would be firestorms[19] (and thus that 95% would not be firestorms). That report has been the impetus for recent attempts to model the mass fires that might result from nuclear weapons effects.[11,18] These models, presented at the NAS symposium, are frequently cited (eg, in the medical literature,[7] in medical school courses on nuclear war, such as the course at the University of Arizona College of Medicine,[20] and in presentations by spokesmen for Physicians for Social Responsibility[21]) as authoritative, recent evidence implying the inevitability and nonsurvivability of firestorms caused by nuclear weapons.

The model for urban superfires presented at the NAS symposium is a statistical combination of the variables influencing target susceptibility to fire. It predicts a wider area of fire damage than previous calculations did, giving 11 km (7 miles) as the mean distance (95% confidence limits: 5.5 km [3.3 miles] to 23 km [14 miles]) to the point at which a 50% probability of fire damage from a 1-megaton airburst would occur.[18(p86)] (Expected overpressure at 11 km is 2.4 psi. At 5.5 km, it is 8 psi and at 23 km, less than 1 psi.[13]) In contrast, the Office of Technology Assessment had previously stated that at the 5-psi level (7.3 km or 4.4 miles for a 1-megaton airburst), about 10% of all buildings would sustain a serious fire, while at 2 psi (13 km or 8 miles for a 1-megaton airburst) about 2% would have serious fires.[22(p21)] A Soviet text warns of the danger of conflagrations in areas experiencing from 3 to 7 psi overpressure, and isolated fires in areas of 1.5 to 3 psi.[23(p55)]

Brode and Small[18] concede some uncertainty in their models:

> There are many variables that influence the prediction of fire size, and thus there may remain considerable uncertainty in damage or casualty prediction. While it may be prudent to assume and plan for the worst case, *it should be noted that smaller values may be equally probable* [emphasis added].[18(p86)]

Aside from dubious assumptions regarding the area of fire damage, models of superfires also make a questionable assumption regarding the extent to which small fires coalesce into superfires. The Office of Technology Assessment stated that the conditions needed to support a firestorm (such as sufficient fuel loading—at least 8 pounds of combustibles per square foot of fire area) are not met in most modern American cities, although mass fires might occur. (Hamburg had 32 lb/sq ft, and the typical American suburb has about 2 lb/sq ft.[22(p22)]) This conclusion has been challenged. Postol states that "attacks on lightly built-up, sprawling American cities, where the amount of combustible material per unit area is relatively low, could well result in extreme conditions somewhat comparable to those of the firestorms experienced in Japan and Germany during World War II."[11(p17)] However, this assertion is based on a large number of assumptions that Postol describes as "highly uncertain"[11(p29)] and "only of the most qualitative nature."[11(p37)] Others who have recently tried to develop criteria for the development of a firestorm state that the requisite fuel loading appears to be about four times the value of 8 lb/sq ft cited earlier.[15(p63)]

Among the uncertainties is the effect of the blast wave from a nuclear explosion, which would level all buildings within a certain radius. If much of the combustible material were buried under masonry rubble, some believe it would be more likely to smolder than to support a firestorm.[24(p4)] A standard Soviet civil defense textbook states: "Fires do not occur in zones of complete destruction [overpressure greater than 7 psi]; flames due to thermal radiation are prevented, because rubble is scattered and covers the burning structures. As a result the rubble only smolders."[23(p55)] The blast wave might blow out an incipient thermal ignition, or it might fan and spread an established fire. It could also expose fuels by breaking up structures.[18(p82)]

Despite all the caveats, Postol concluded that superfires "would accompany nuclear detonations in or near urban areas,"[11(p69)] and Brode and Small considered "area fires" even larger than those of World War II to be "likely."[18(p94)] Not all participants in the NAS symposium agreed. Lynn Anspaugh, Project Leader for Lawrence Livermore National Laboratory's studies on the biologic and ecologic effects of global nuclear war, noted that:

> There is speculation that "superfires" might occur, but there are *no firm data on which to base such speculations*; and it is fair to say that there is simply no basic understanding of the physics of the process such that one can predict with any certainty the essential requirements for the production of a superfire [emphasis added].[25(p567)]

Further, he observed "an unusual willingness in the participants in the symposium to accept the offered predictive results and speculations at face value."[25(p577)]

The question of whether firestorms might occur or of how frequently they might occur after a nuclear attack appears to be unresolved. Given the *possibility* of a firestorm under certain circumstances, how useful would shelters be in such an event?

SHELTERS IN HAMBURG

Several different types of shelters were constructed in Hamburg. Some were above ground because of the high water table in many sections of the city. Most of the private shelters were simply basements. Despite difficulties occasioned by wartime shortages of fuel, concrete, and steel, public shelters were available for about 25% of the total population in Hamburg in July 1943, including the following: 1,442 public air raid shelters with a capacity of about 197,000 persons, 773 "splinterproof" *(splittersichere)* shelters with a capacity of about 103,000, and 139 "bombproof" *(bombensichere)* bunkers with a capacity of about 79,000.[3(p16)] Some public air raid shelters were converted from large cellars by the addition of beams and supporting columns.[1] Others were located in business districts, as in the middle of a wide street, with the top floor about 3 m below ground. Splinterproof shelters, which could not withstand a direct hit by a high-explosive bomb, were constructed in a trench slightly below ground, covered by an unreinforced concrete slab about 0.6 m thick.[26(p143)] Bunkers were of heavy reinforced concrete, 2.5 m thick.[3(p165)]

The actual occupancy of shelters during the firestorm can only be estimated. During heavy air raids, shelters were extremely overcrowded, occupied at two to three times[27,28(p118)] or in some cases up to five times their stated capacity,[26(p142)] so the occupancy cannot simply be taken to equal the capacity. If one assumes that the distribution of shelters within the firestorm area was characteristic of shelters within Hamburg as a whole, and that bunkers sheltered twice their stated capacity, the following population distribution can be estimated for the firestorm area: splinterproof shelters, 25,000 persons; bunkers, 28,000; other public shelters, 45,000; private shelters, 182,000; total population, 280,000. (The entire population was assumed to be, at least initially, in some type of shelter, because of intense air raids on the previous night.[1(p10)]) Actually, in the residential districts where the firestorm was extremely intense, there were few public shelters and most persons were in basements beneath tightly-packed, tenement-style apartment buildings.[16(p271)] However, this estimate for the number sheltered in bunkers agreed with one made independently on the basis of a British Home Office Civil Defence intelligence bulletin and exhibits in the US Strategic Bombing Survey.[1(p10)]

CASUALTIES IN HAMBURG

The British Home Office reported about 40,000 killed during the Hamburg firestorm.[1] The death rate was highest in the Hammerbrook residential district, where nearly a third of the population perished in the flames.[14(p83)] According to preliminary German figures, the death toll was 31,647 persons[3(p40)]; later, the number was increased to 51,175,[12(p401)] including those who died of injuries. About 4,000 serious injuries and about 20,400 less serious injuries were treated in established first aid centers.[14(p91)] Contrary to expectations, reconstruction projects over the last three decades, especially in the firestorm region, have revealed few additional victims. This attests to the thoroughness of the initial rescue operations.[12(p401)] Thus, about 230,000 persons (82% of the 280,000 estimated to be in the firestorm area) survived, despite the inadequacy of many of the shelters.

Most of the dead were found in the streets or in basements. In public shelters, the death toll was as follows: in splinterproof shelters, 96 dead, all in a single shelter that suffered a direct hit; in bombproof shelters, two dead; in slab shelters, four dead; in "public air-raid shelters" in houses (most of them beneath multistoried, heavily timbered structures), 2,918 dead.[12(p280)] Survivors were accounted for as follows: 53,000 survived in nonbasement shelters; 30,000 were rescued by police, medical, rescue, and armed forces; 15,000 were rescued by fire and decontamination services; and about 142,000 either survived in basement shelters or escaped by their own initiative.[1(p14)] (These British estimates were based on the earlier report of 40,000 casualties.)

Many gruesome descriptions have been published of conditions in some shelters.[10,16,28] As Earp noted, "on reading the descriptions, perhaps somewhat highly coloured, of conditions in these [basement] shelters, one is left with the impression of a very high proportion of casualties."[1(p13)] Nevertheless, the mortality statistics show that 80%, even of the cellar shelterees, survived.[1(p13)]

The death toll was low in proper shelters despite the fact that:

> Many air protection bunkers and splinterproof surface shelters were situated in the middle of extensive area fire and firestorm zones. The heat around these buildings was more than human beings could stand.... Shelterees remained in many of these structures until the morning after the raid and

TABLE. Firestorm Casualties[17,18(p76),31]

City	*Deaths*	*% of Population "At Risk"**	*Comments*
Hamburg	50,000	18%	
Dresden	135,000		Estimates of city population vary widely.
Kassel	6,000-9,000	8%	Chemical fireproofing of roofs and independent fire hydrant system reduced spread of fires.
Darmstadt	8,000-15,000	12%	No air raid bunkers.
Brunswick	560	<1%	23,000 people survived in six giant bunkers and two public shelters; 93 died of asphyxiation in one shelter.
Heilbronn	6,000-8,000	17%	
Tokyo	84,000†		Compare with about 71,000 killed at Hiroshima.

*Population "at risk" includes population in firestorm area and not in shelters of fireproof construction.[31]
†US Army and US Air Forces records. Others claim that 200,000 died.[32(p 385)]

until the fires surrounding them had abated. In some cases a covering of [cooling] water had to be supplied at the exit by the Fire and Decontamination Service in order to get the inmates out.[3(p161)]

One person who survived in a bunker in Hammerbrook reported that when she emerged she had to step through the fat of the molten bodies of those who had come to the shelter too late.[16(p271)]

One possible source of misunderstanding about survival in shelters may be a statement by the Police President that "only those got away who had risked an early escape or happened to be so near the edge of the sea of fire that it was possible to rescue them."[29] In proper context, this sentence refers to persons who remained in the basement of their home or tried, too late, to flee, not to those who took refuge in nonbasement shelters. In his conclusion to the report, the Police President stated:

> If the number of casualties is not higher by a multiple, . . . if a large quantity of wares, goods, and raw materials of all types was saved from destruction, this is exclusively to be credited to the air defense service. . . . The limited successes have not proved the purposelessness of air protection; all air defense measures . . . were shown to be unconditionally necessary.[3(pp181-182)]

Further, he stated that "the air raid bunkers have proved themselves very well in particular because of their insensitivity to fire and heat."[3(p162)]

CAUSE OF DEATH IN SHELTERS

It is claimed that persons in shelters would perish in a firestorm from lack of oxygen. In fact, probably no one in Hamburg died of this cause.[12(p265)] There is a close relationship between the amount of oxygen necessary for human survival and the amount necessary to support combustion. The continuation of active burning thus constitutes evidence that the oxygen concentration in the vicinity has not dropped below the level necessary for survival.[30] The amount of oxygen needed to burn completely the typical single family residence is contained in a column with base equal to the area of the house and height of just a few hundred feet. Given the turbulent air currents in the region of a fire, any general depletion of oxygen would be momentary at worst.[30] As to the claim that air will be sucked out of a shelter (implying the creation of a strong vacuum), there is no evidence to indicate that anything but a slight drop in pressure can possibly occur.[30]

Although oxygen depletion due to the fire itself is not expected, asphyxiation due to lack of ventilation in a crowded shelter is a possibility. Carbon dioxide accumulation would be a problem before oxygen depletion. However, at a December 1943 conference attended by pathologists, medicolegal experts, and physiologists, all having extensive experience with the outcome of incendiary raids, the majority concluded that deaths from anoxia and carbon dioxide excess had not been substantiated.[27,28(p114)] In bunkers, the ventilation systems frequently had to be shut off because of heat, smoke, and toxic fumes. Still, the air remained breathable, even in bunkers that had been occupied for days by the homeless or that had had their occupancy limits exceeded many times.[3(p162)]

Of those who did die in basements in Hamburg, the majority probably perished from carbon-monoxide poisoning.[3(p16),12(p265),27] These victims, who were fully clothed, appeared to have fallen asleep peacefully. There was no sign that they had been struggling to escape from unbearable heat.[12(p291)] Elevated blood levels of carbon monoxide in firestorm victims were documented by chemical analysis, as reported to the Police President of Kassel.[17(p236)] In many victims, this cause was suspected but could not be proved because of the unreliability of the tests in persons dead for more than a few hours.[28(p120)] Other causes of death in basement shelters included heat exhaustion and mechanical causes, such as burial under rubble from the collapse of the burned-out houses above.[28(p119)]

OTHER FIRESTORMS

Other cities were also subjected to fire bombing, and approximate casualty figures are listed in the Table.[17,18,31,32] Firestorms "frequently killed more than 5% of the population"[18(p75)] (so that about 95% survived). The death rate was influenced greatly by the adequacy of defensive measures.

The worst carnage occurred in Dresden, where the population was swollen with refugees. Because the authorities did not expect Dresden to be bombed, it was not considered necessary to build huge concrete and steel bunkers of the kind that had saved the lives of hundreds of thousands in other targeted cities, and the inhabitants were totally unversed in civil defense practice.[17(pp166-168)] The usual source of statistics about air raid casualties, the Police President's report, either was never written or did not survive the war. The Dresden official in charge of the *Abteilung Tote* of the Bureau of Missing Persons estimated that about 135,000 died. Many of these casualties were preventable:

> Had the half-hearted A.R.P. [air-raid protection] measures in Dresden been completed, had there been adequate provision of properly ventilated bunkers, as in other German cities then and now, then the catastrophe which befell Dresden during the fourteen hours of the triple blow could have been averted.... Over a hundred thousand of the city's civilian population were now to pay for their leaders' lack of foresight with their lives.[17(p170)]

There were, nonetheless, survivors in Dresden shelters. One of them was American novelist Kurt Vonnegut, who was a prisoner of war at the time. He described his experiences in the book *Slaughterhouse Five.*[33]

Although a firestorm may have occurred at Hiroshima, there are no references to people in the streets succumbing to heat or carbon monoxide as they did in Tokyo or Hamburg,[34(p18)] suggesting that the mass fire was considerably less intense.

THERMAL EFFECTS OF NUCLEAR WEAPONS

In a nuclear war, fire would be fiercely destructive and could cause more casualties than blast and radiation.[35(p586)] This fact was recognized early, but at times has been forgotten.[36] (At Hiroshima and Nagasaki, burns caused at least 50% of the initial casualties.[28(p211)])

In a nuclear detonation, about 35% of the energy is released as heat. The temperature at the center of the fireball reaches 100 million degrees Kelvin,[11(p15)] and at its surface a maximum of 8,000 degrees Kelvin. The thermal pulse is of short duration. In a 1-megaton airburst, 80% of the thermal radiation is emitted in 10 seconds.[13(p314)]

Whether an object will be ignited by the thermal pulse depends on the radiant exposure (which depends on such factors as the distance from ground zero, the yield of the weapon, and the atmospheric conditions) and the ignition energy of the material (which depends on the color, the type of material, the relative humidity, and the duration of the heat pulse).[13] As an illustration, a 1-megaton airburst could deliver 10 cal/cm^2 at a range of 6 km (3.75 miles), if visibility is 20 km (12 miles). This could ignite some light fabrics and perhaps other easily combustible items.[11(p29)] At Hiroshima, telephone poles charred, roof tiles bubbled, and thatched roofs and other easily ignited materials caught fire.[34]

The thermal pulse travels in a straight line, and objects that cause shade offer partial or total protection. A shield as flimsy as a bedsheet would suffice.[37(p36)] At Hiroshima, a clump of grass or tree leaves was in some cases adequate, implying that the duration of the flash was less than the time required for the grass or leaves to shrivel.[34(p25)] The children whose horrible burns are shown in documentaries of Hiroshima would probably have escaped these injuries had they been sitting under their school desks when the blast occurred.[38(p26)] Filmstrips produced for the instruction of Soviet citizens in civil defense illustrate this point. One frame is evidently based on photographs from Hiroshima, showing a woman with normal skin beneath the light-colored fabric of her kimono, and burns beneath the dark fabric.[39]

Various measures for reducing ignitions due to the thermal pulse have been tested by the US government in atmospheric nuclear explosions, as at Operation Upshot Knothole in Nevada. A frame house that was well maintained and had painted wood siding and a clean yard showed only minor scorching after the detonation. A house with unpainted and weathered siding, at an identical distance from ground zero, suffered smoldering ignition and later burst into flames. A third house, which was poorly maintained and surrounded by dry weeds, burst into flames immediately.[36]

Soviet citizens are instructed in measures for reducing ignitions, such as whitewashing buildings and removing drapes from the windows, in the event that an attack is believed to be imminent. Civil defense classes and drills include extensive instruction in firefighting techniques. The danger of nuclear attack is also taken into account in the construction of Soviet cities. Streets are very wide to reduce the risk of blockage by rubble and to impede the spread of fires.[40]

Fires can also be caused by secondary effects of a nuclear blast, eg, electric short circuits and ruptured gas lines.

Although secondary fires caused few burns among the survivors of Hiroshima, it is likely that a large number of people died by being trapped in burning buildings.

In evaluating the incendiary potential of nuclear weapons on the basis of the experience at Hiroshima, where the destruction appeared much like that after conventional incendiary raids, it must be remembered that Japanese cities were far more susceptible to fires than German ones. In the densely packed Japanese construction, 95% of building materials were flammable. Based on a study of the fires resulting from the Japanese earthquake in 1923, which took 100,000 lives, Billy Mitchell proposed a secret plan in 1924 for the use of incendiaries in the event of war against Japan. Bombing experts estimated that 2.1 kilotons of conventional bombs (of which half were incendiaries) could have caused the same degree of damage to a Japanese city as the atomic bomb.[41]

In considering the lessons of World War II firestorms for the design of shelters against nuclear weapons, the hazard of locating shelters near combustible structures has been emphasized.[36,42] Carbon monoxide poisoning would be a serious threat unless the shelter could be sealed off for a sufficient time. This problem could be avoided by proper selection of shelter sites. A 1968 study of the inner city of Detroit by Bechtel Corporation showed that an adequate number of such locations could be found so that the average distance to shelter would be 0.8 km (0.5 mile).[43]

Regardless of the cause of the fire (nuclear weapons or conventional incendiaries), an hour or two of active burning will consume the fuel available in a single location. During that period, heat transfer into a shelter through 3 ft of earth or its equivalent is negligible.[30] (On the other hand, smoldering rubble piled high above a shelter could cause a heat problem.[30])

Although it is speculated that firestorms caused by nuclear explosions might extend over larger areas than the firestorms of World War II,[18] Broido[30] noted that the largest fires of the past were sufficiently large that no new factors would be expected to influence the environment within the fire zone. He stated that to people in the center of a mass fire at least 1.67 km (1 mile) or so in diameter, the fire is already infinitely large, and the environment would be no different if the fire were even a thousand times larger.[30(p21)] More recent models have predicted that the maximum induced wind velocity and maximum temperature would increase with the radius of the firestorm as well as with the fuel loading. For relatively small radii (less than 10 km), maximum wind velocity and maximum temperature are predicted to increase as a nearly linear function of the radius; for larger radii, the velocity is predicted to level off at about 40 m/sec (89 mph) and the temperature at 600 degrees Kelvin (337 C). Thus, the wind velocities (though not the temperature) "may be even greater than those encountered in the 1943 Hamburg firestorm"[44(p83)] (assuming the lower estimates of the Hamburg wind velocities).

OTHER IMMEDIATE EFFECTS OF NUCLEAR WEAPONS

The blast wave from the detonation of a nuclear weapon would cause huge numbers of casualties in unprotected populations. The radius of the lethal zone would depend upon the yield of the bomb or the weapon and the burst height. For relatively small weapons (like the one used at Hiroshima), the initial nuclear radiation would cause additional casualties among those who survived the blast. If the weapon were surface burst, then deadly radioactive fallout would imperil persons hundreds of miles away.

Shelters against such weapons effects were developed early in the nuclear age. Tests of shelters were included in actual atmospheric tests of nuclear weapons from 1951 through 1958. After the Test Ban Treaty of 1963, testing was begun by both Canada and the US with large high-explosive charges to simulate nuclear weapons. Despite some limitations to the use of high-explosive techniques, most of the blast effects of nuclear weapons can be simulated, giving a high level of confidence that a shelter so tested will perform as expected in a nuclear weapons environment.[45(p90)]

Some shelter designs have been proved capable of withstanding overpressures of more than 300 psi. (An overpressure of 200 psi would be sustained at a distance of about 0.5 miles from ground zero of a 1-megaton airburst.[13]) In Operation Plumbbob (carried out in Nevada in 1957), cylindrical structures of 10-gauge corrugated steel and of concrete sewer pipe were buried at depths of 1.5 to 3.0 m (5 to 10 ft). Pressures as high as 149 psi and radiation in excess of 100,000 rad were experienced above ground (as would occur at about 1 km or 0.6 mile from ground zero of a 1-megaton airburst[13]), but there was negligible deformation of all of the shelters and negligible radiation levels were recorded inside.[45(p84)]

Many varieties of expedient shelters were tested at the Dice Throw event in 1976, including a Russian small-pole shelter at 53 psi.[45(p87)] The instructions for building such structures[46] have also been successfully field tested in experiments employing ordinary Americans as volunteers. A recent demonstration was conducted by the Oregon Institute of Science and Medicine. One of the shelters, a car-over-trench fallout shelter, was built by three women, all over 60 years of age, using only hand tools.[47]

Habitability testing of various shelters has also been carried out, for periods up to two weeks.[45(pp90-96)] The length of shelter stay required would depend on numerous variables, such as the targeting strategy, weapons yields, and weather conditions. One recent analysis concludes that except in regions of heaviest fallout, the sheltering provided by an unprepared basement with a shelter time of no more than three weeks would permit most persons outside the zone of other lethal weapons effects to survive.[48]

It is always possible to postulate an attack that would destroy any given shelter. For example, no shelter would survive in the middle of the crater made by a surface burst. However, shelters would greatly diminish the lethal area for any given bomb:

> So far as the effects of blast are concerned, people in Swiss shelters would be killed by a given bomb in less than a quarter of the area within which people without shelters would be killed by the same bomb. So far as the effects of radiation are concerned, people in Swiss shelters anywhere outside the area of lethal blast damage would have a reasonable chance of survival. These two statements are worded in such a way as to be true independently of the size of the bomb.[38(p86)]

Soviet civil defense manuals state that sheltered persons near the periphery of the "first zone" of nuclear destruction (more than 14.4 psi overpressure) might be alive, but require rescue because of the rubble. In the "second zone" (4.3 to 14.4 psi), most of the shelterees are expected to survive.[49(p114)] A review of monthly Soviet civil defense reports from 1955 through June 1988 shows no change in teachings about weapons effects.[50] Although the attitude of Soviet citizens toward civil defense may have been influenced by recent telecasts (for example, one in which A. P. Aleksandrov, President of the USSR Academy of Science, stated that nuclear war would make the planet uninhabitable), the Soviet civil defense program totally disregards this type of presentation and "in no way suggests that there are any grounds for questioning or reassessing the utility or effectiveness of civil defense."[51(pp65-66)]

In the two actual wartime detonations of nuclear weapons, few persons were sheltered. These cities were not thought to be targets. Furthermore, the people were not aware of the awesome destructive potential of a single bomb, and the air raid alarms were not maintained upon the approach of the airplane that was carrying it. In Nagasaki, investigations showed that scarcely any of the approximately 400 persons who were in tunnel shelters at the time of the attack received burns or serious injuries. This fact gives credibility to the estimate that 30% of the deaths and injuries could have been averted had the tunnel shelters been filled to their rated capacity.[52(p6)] Carefully built shelters, though unoccupied, stood up well in both Hiroshima and Nagasaki.[28(p237)]

At Hiroshima, persons who were in buildings of better construction had a fair chance of survival. Between 0.5 and 1.25 km from ground zero, where casualties in the open ranged from 90% to 100%, the casualties in buildings varied with the degree of structural damage (among other factors). In buildings sustaining light damage, 51% of the occupants escaped injury.[13(p547)]

CONCLUSIONS

The experience in Hamburg and other cities in World War II shows that *properly constructed* shelters can prevent most deaths due to fire, even in areas of intense firestorms. Shelters can also reduce substantially the area of lethality due to other effects of nuclear weapons. If shelters are *not* available, as is now the case in the US, nuclear weapons will cause a larger number of casualties.

Medical recommendations related to population protection (or lack of same) appear to be based on erroneous reports that refer to the Hamburg firestorm as nonsurvivable and that omit mention of shelter test results.

A reexamination of such recommendations would appear to be indicated, if one accepts the premise that public policy should be founded on the best available assessments of weapons effects and protective measures, not on historical misinformation and "worst case" models.

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